# A NANOSATELLITE TO DEMONSTRATE GPS OCEANOGRAPHY REFLECTOMETRY

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**ABSTRACT:** This paper describes a proposal for a rapid, low cost, nanosatellite mission to demonstrate the concept of GPS ocean reflectometry and to investigate the feasibility of determining sea state for a future operational space-based storm warning systems.

The aims of this mission are to prove the general feasibility of GPS ocean reflectometry, to demonstrate sea state determination and to enable the development of a practical GPS ocean reflectometry payload for future missions. The payloads on the satellite consist of a 24 channel C/A code SGR-10 space GPS receiver and a solid state data recorder. The GPS receiver has one standard RHCP zenith antenna, and one high gain LHCP nadir antenna for receiving the reflected signals. A dual approach is taken to measurement gathering. Initially, bursts of directly sampled IF data are stored and downloaded to permit processing of the data on the ground. Later in the mission, the GPS receiver software may be modified to permit the processing of signals on-board the satellite.

The nanosatellite is based on SSTL's *SNAP* design and has a projected total mass of around 12 kilograms; orbit average power of approximately 4.8 watts; 3-axis attitude control to 1-2 degrees; VHF uplink, S-band downlink at 500 kbps, and OBC based on the StrongARM SA1100. Using the SNAP design enables a fast manufacture at low cost: estimated at 9 months and around 2 million Euros, including launch. The proposed mission makes use of the Surrey Space Centre Mission Control ground-station in Guildford (UK) for control and data gathering.

Surrey Satellite Technology Ltd (SSTL) is a world leader in both nanosatellite and GPS technology for small satellites. SSTL's highly successful SNAP-1 nanosatellite launched in June 2000 demonstrated the potential of such small spacecraft, and this proposal involves the first ever use of a nanosatellite for a commercial application (GANDER) in collaboration with SOS Ltd (UK) a company specialising in oceanography from space.

## 1 INTRODUCTION

### 1.1 Background

This paper describes a rapid low cost nanosatellite mission to demonstrate the concept of GPS ocean reflectometry and to investigate the feasibility of determining sea state for a future operational space-based storm warning system. It includes various simulations, and also some space-based tests undertaken using SSTL's UoSAT-12 minisatellite for qualification of the reflection point algorithms.
Surrey Satellite Technology Ltd (SSTL) is a leader in both nanosatellite and GPS technology and SSTL's highly successful SNAP-1 nanosatellite [1] launched in June 2000 demonstrated the potential of such small spacecraft. The proposed mission would be the first ever use of a nanosatellite for a genuine practical application, fully making use of the low cost and fast schedule available as a result.

### 1.2 Mission

The aims of this mission are to prove the general feasibility of GPS ocean reflectometry, to demonstrate sea state determination and to enable the development of a practical GPS ocean reflectometry payload for future missions. The payloads on the satellite consist of a 24 channel C/A code SGR-10 space GPS receiver and a solid-state data recorder. The GPS receiver has one standard RHCP zenith antenna, and one high gain LHCP nadir antenna for receiving the reflected signals. A dual approach is taken to measurement gathering. Initially, bursts of directly sampled IF data are stored and downloaded to permit processing of the data on the ground. Later in the mission, the GPS receiver software may be modified to permit the processing of signals on-board the satellite.

The nanosatellite has the following characteristics:

- Total mass of around 12 kilograms;
- Orbit average power of approximately 5 watts;

- 3-axis attitude control to 1-2 degrees,
- VHF uplink, S-band downlink at up 500 kbps,
- OBC based on the StrongARM SA1100.

The mission makes use of SSTL's ground-station in Guildford for control and data gathering.

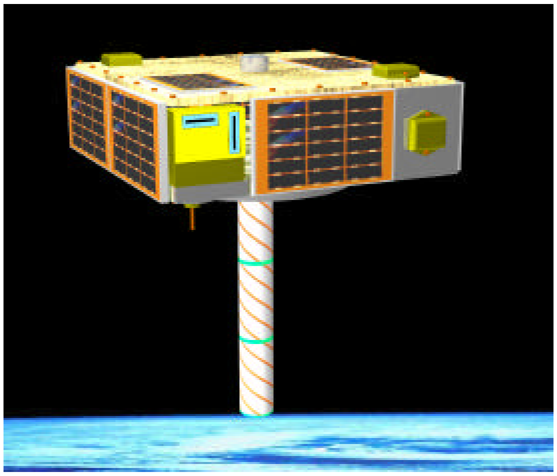

**Figure 1 GPS Ocean Reflectometry Satellite in Orbit**

### 1.3 Mission Goals

This fast turnaround, low cost, proof of concept, Pathfinder mission is based on SSTL's successful, flight proven SNAP-1 nanosatellite and embraces the following objectives.

- To demonstrate the feasibility of measuring reflected GPS from the sea surface, and offer a reflectometry test-bed
- To develop and demonstrate a practical GPS remote sensing payload for a future operational mission or constellation
- To store and forward GPS data to enable assessment of sea state to be made

Specific investigations to be undertaken include:

- Reflected signal strength measurement
- Delay mapping of the return signal due to sea state
- Use of attitude control to provide the ability to measure sea state at specific geographic locations (Some of this has been demonstrated using UoSAT-12, targeting and imaging optical reflections from the Sun)

## 2 RATIONALE

This pathfinding nanosatellite mission will enable low cost determination of the usefulness of GPS constellation signals for monitoring sea-state. The mission should also highlight the strengths and weaknesses of this method as compared to radar altimetry measurements. Should this prove to be an adequate method of determining sea state, a very low cost constellation can be implemented to provide warning of local sea state to mariners before they enter a region of stormy seas.

### 2.1 GNSS-Based Ocean Reflectometry

The concept of passively receiving signals from Global Navigation Satellite System (GNSS) satellites as an alternative to active altimetry was developed by Martin-Neira at ESTEC in 1993 [2], and is being actively pursued in the context of ESA's PARIS programme. A GPS receiver on a high altitude platform can be configured to receive both direct GPS signals and signals reflected off the ocean at the specular point of reflection. These reflections are affected by sea height, wave height, wind speed and direction, and so by analysing the characteristics of the reflected signals, a wealth of parameters is potentially available. The thrust of the PARIS programme is to make full use of the GPS/GNSS signals available to obtain phase-coherent reception of multiple frequencies such that calibrated centimetric accuracy measurements can be made.

Techniques associated with the reception of reflected GPS signals have been investigated in numerous studies, but there is still a serious lack of practical experience, and an early demonstration of the concept in orbit would be welcomed by members of the oceanography community across the world. The DLR CHAMP mission is the first and only satellite to have a dedicated GPS surface reflection experiment (GOPE), but this is a low priority experiment dependent on extensive software development in the receiver by NASA JPL.

### 2.2 The Need for Sea State Determination

Accurate knowledge of significant wave height can be used to provide improved warnings to mariners of severe weather conditions. Loss of life, injury and huge economic losses are incurred every year due to lack of local sea state information at the required temporal frequency. Detection of severe sea state conditions is currently inadequate and forecasts are generally not regarded as trustworthy due to the large spatial and temporal resolution of the grids used.

Meteorological forecasts are based upon inputs of barometric pressure and wind speeds largely derived from land based weather stations. Ship based reporting is patchy, and subject to considerable error in respect of wind speeds and wave heights. Satellites provide the ideal stable platform for global monitoring of sea conditions, from which meteorological models may be calibrated and validated. Existing meteorological satellites monitor cloud formations.

The only system that monitors the sea surface is 'Sea State Alarm', which uses near real-time data from the ERS-2 radar altimeter to detect wave heights. This is currently updated twice per day and is available within 4-6 hours via email. Deficiencies are that distances of up to 2500 km between tracks, erratic availability and closest approach of typically 500 km in 3 days are typical. Proposals are under consideration to measure wave heights as an operational service with a constellation of radar altimetry microsatellites called GANDER.

## 3 MISSION DESCRIPTION

The satellite is based on the SNAP-1 nanosatellite, as launched in 2000. SNAP has been designed according to similar cost-effective principles that have proved so successful on previous SSTL missions and is compatible with a range of affordable launch options.

By making use of the existing systems as far as possible, the low cost and rapid schedule is possible, whilst retaining flight heritage. As the launch is one of the most significant costs, a launch of opportunity is assumed, and this will define the orbit parameters. The nanosatellite platform can operate in a range of Low Earth Orbits and is designed for a one-year nominal mission lifetime, with extended life expectancy.

### 3.1 Payload Overview

The two payloads required to fulfil this mission are the GPS receiver, and a solid-state data recorder. The SGR-10 Space GPS Receiver (Figure 2) has 24 C/A channels at L1, which can be allocated to two antennas. One standard GPS antenna will be placed zenith pointing on the space facet of the satellite for normal GPS positioning operation. The second antenna will be a higher gain Left Hand Circular Polarised (LHCP) antenna pointing downwards at an angle from nadir to pick up GPS signals reflected by the ocean.

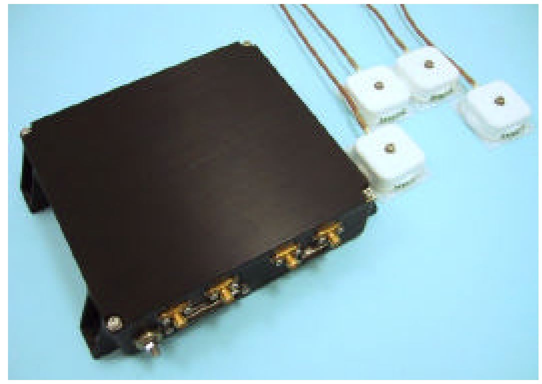

**Figure 2 SGR-10/20 Space GPS Receiver**

The initially selected gain for the nadir antenna is 12 dBi, and antenna off-pointing angles (from nadir) from 0 to 45 degrees have been considered, but these parameters will be analysed and refined based on a trade-off between system performance and practical satellite constraints, given a selected orbit. The nadir GPS antenna may be implemented by use of a helix antenna; a cupped helix (sometime called "heli-bowl") or quadrifilar helix antennas may be suitable options. An air/vacuum-cored helix antenna of approximately 36 cm can provide a gain of 12 dBi. If a higher gain antenna is required (e.g. 15 dBi), the use of a dielectric core may be necessary to retain a sufficiently small size for the nanosatellite.

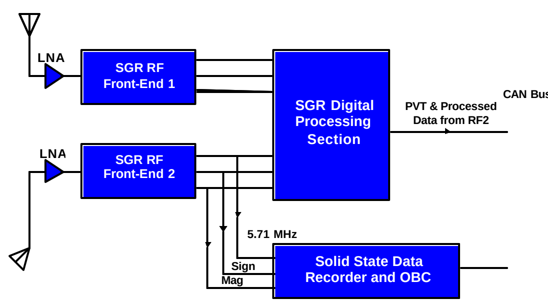


**Figure 3 GPS and Data Recorder Payload Configuration**

The signals tracked from the zenith antenna can be processed directly by the GPS correlator hardware to yield accurate position, velocity and time solutions, and to produce raw GPS measurements (i.e. pseudoranges, Doppler shift, carrier phase, and signal to noise ratios) for download.

The signals received by the nadir-pointing antenna will have been affected by the ocean state, and the essence of this experimental mission is to analyse how these effects are manifested in the reflected signals. To fully analyse the data, it is necessary to process the sampled data on the ground, where a number of techniques may be employed to characterise and understand the results. Therefore, a solid state data recorder is used to record the two bit sampled signals from the nadir antenna after the RF section downconversion.

The SGR-10 GPS receiver may be reconfigured to process the reflect ed signals on-board the satellite directly. The hardware architecture of the receiver has similarities to the delay-mapping receiver used by NASA and others for exactly this purpose [3], and software may be uploaded while the experiment is in orbit. Twelve channels are available for measuring the correlation spread of the signals from one reflected GPS satellite signal due to the ocean state. With experience gained from the ground-based processing of the sampled data, potentially the software of the SGR can be optimised to directly take measurements of the wind speed and surface slope of the ocean without requiring the downloading of sampled data.

The solid-state data recorder is included as an additional function of the nanosatellite's on-board computer (OBC). The data recorder/OBC is based on the SNAP OBC, and makes use of the StrongARM processor. The data recorder will be given a 5.71 MHz clock by the GPS receiver and will use that to latch in the 2 bit samples from the nadir RF front-end.

### 3.2 Operations

In the nominal phase of the mission, GPS signals from the zenith antenna will be logged at a low rate over the period of one or more orbits to obtain good orbit knowledge. Then the nadir GPS satellite antenna would be steered to a specified direction such that it should be pointing at a GPS signal reflection from the ocean. Position, velocity, time and raw measurements from the zenith antenna, gathered over an orbit plus the short burst of 2-bit sampled data from the nadir GPS front-end, will be logged by the data recorder until its capacity is reached. This data will be downloaded via the nanosatellite S-band downlink.

The use of the GPS correlation hardware to process the signals on-line will be a natural extension of the mission. If autonomous processing can be achieved, the satellite will be able to take many more readings, and for longer periods, as the data download requirements will be significantly less.

### 3.3 Target Selection

The potential target zones of operation must be carefully selected such that the chances of receiving one or more GPS signals are maximised, and such that the results can be cross-compared with known data on the surface. The calibration issues will require close collaboration with oceanographers. Initial measurements would be taken where the sea is most likely to be flat to achieve maximum specular reflection. Regions will be targeted where it is known that accurate measurements of the sea state are regularly taken. To fulfil both these requirements, candidate targets might include equatorial seas near archipelagos, for example, or following in the path of another remote sensing satellite taking appropriate measurements.

### 3.4 Reflection Point Identification

Preliminary code for identifying good candidate targets for reflected GPS signals has been implemented in the GPS receiver and tested. While the space-facing antenna is tracking all visible GPS satellites (normally between 5 and 11) the downward looking antenna will need to concentrate its efforts on one or more of the GPS satellites with geometry favourable to providing a visible ocean reflection. Prior work on the geometry of the reflected signal [2] has been used to help with the implementation in the receiver processor. The equation for the secular point can be written in the form of a spherical mirror equation, but due to the limited processing bandwidth of the onboard processor, every effort was needed to streamline the efficiency of the real-time calculation on the platform. The solution undertaken for this satellite does not solve for the 4 roots of this equation in the firmware but iteratively searches for a valid solution to Snell's law over a valid range of possible reflection points.

By rotating the receiver and transmitter coordinates from Earth Centered Earth Fixed (as normally computed by the receiver) into the reference frame of the candidate reflection point (on the surface of the earth) it is then possible using the law of cosines and other basic trigonometric functions to test for a valid solution of Snell's law over a limited region. Not only does the reflection have to be tested for geometric validity, but it needs to be determined if the specular point occurs over land or water. These tests are performed using a bitmap in the software that tests the calculated latitude and longitude of the specular point and returns a true if the point resides over the ocean.

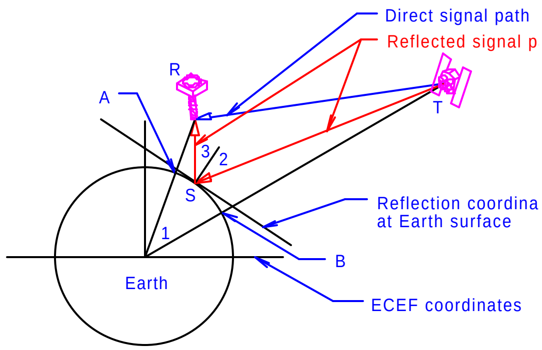


**Figure 4 Signal Geometry of a Reflected GPS Signal**

Figure 4 illustrates this procedure: the receiver and transmitter locations are represented by the labels R and T (not to scale). The arc between the receiver and transmitter sub-satellite points on the surface of the earth is calculated (shown as points A and B). If a valid reflection exists it will be on this arc. The arc is then intelligently searched until the reflection angle between the receiver and the earth normal and the transmitter and the earth normal are equal (angles 2 and 3). The magnitude of angle 1 below is used to determine the search arc as well as to verify the validity of the point (the signal path does not intersect the Earth for example) and establish search bounds. From this we derive the characteristics of the specular or reflection point (point S).

### 3.5 Simulation results

Results obtained for an example trial for a visible GPS reflection are shown in Figure 5 below. It illustrates the sub-satellite ground points of the transmitter (red) and the receiver (pink) with the surface arc traced out in equidistant intervals (yellow). The reflection point is represented by the white circle in the line of the yellow stars closer to the receiver.

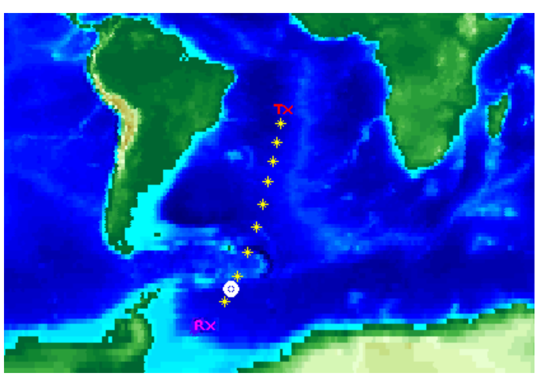


**Figure 5 Finding the specular point on an arc**

The specular point moves all the time, as both the receiver and the GPS transmitting satellite move. A simulation of multiple GPS spacecraft tracked by a moving small satellite is shown in Figure 6 below. The green track is the nanosatellite, the white stars the instantaneous specular points.

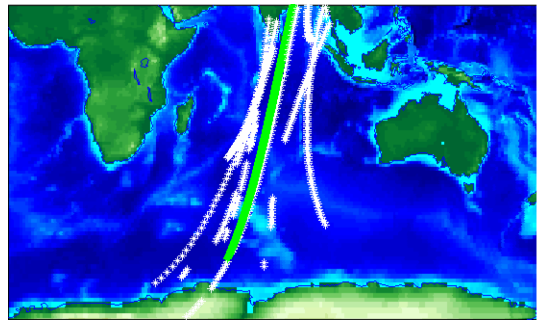

**Figure 6 Specular points from multiple GPS satellites over approximately 20 minutes**

Detailed analysis of reflections of opportunity from a space borne reflection experiment [6] has shown dependence on several other factors including satellite orbit and antenna pattern. For our trials there was no modelling of the antenna pattern or even of the receiver or GPS satellite orbit. Our goal was to demonstrate that for any combination of transmitter and receiver positions (at selected altitudes, 700km in the above example) we could determine the necessary variables for a possible acquisition and tracking scheme on an Earth facing antenna. The variables of concern included: reflection angle and path delay, secular point location, and a flag indicating if the secular point is over land or water and valid. This information provides the initial steps. From here the Space GPS Receiver is configured in one of several possible ways for acquiring the reflected signal and tracking it at various doppler and code offsets to determine the reflected signals waveform and hence an indication of the ocean state at the reflection point.

### 3.6 UoSAT-12 Optical Confirmation of Specular Point Determination

In order to try out the specular point algorithms in space, the UoSAT-12 minisatellite was recently programmed to use its optical cameras to point at the calculated coordinates of the sun's reflection, and take an image. The calculated path is shown in Figure 7: The Sun position is indicated by the red dots, the spacecraft by the green trail, and the calculated reflection points by the white trail.

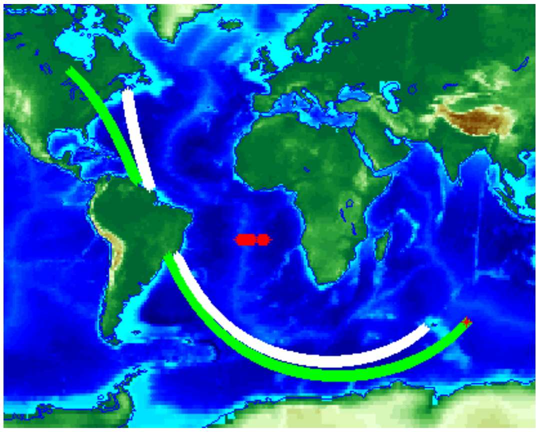

**Figure 7 Sun reflection points**

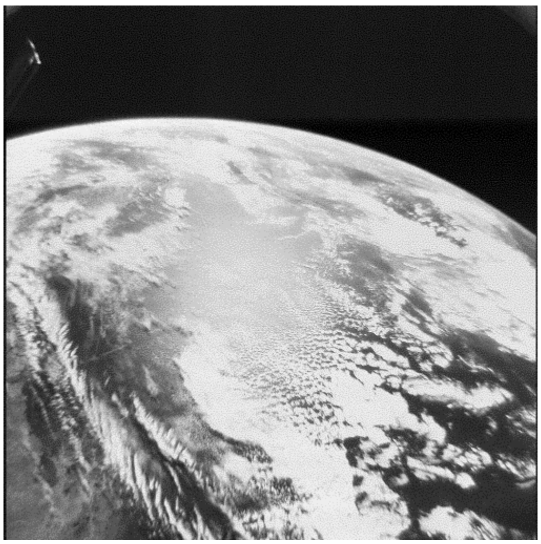

**Figure 8 Image of the Sun's reflection**

The entire spacecraft was then rotated to point the normally Nadir pointing cameras to the specular point. As shown Figure 8 this was successfully achieved: the Sun's reflection can be seen close to the centre of the image.

### 3.7 Processing of Data

The nominal data processing technique employs the same techniques as a standard GPS receiver, but is extended in order to analyse the nature of the reflected signal. Firstly, the GPS code that modulates the signal is known, and estimates of the code and carrier can be obtained using geometry and the positions and velocities of the GPS satellite, the nanosatellite, and the mean sea level. Then the carrier and the code can be removed using signal processing.

The code correlation process is adapted such that the cross-correlation magnitude at different code delays can be found. The availability of the actual sampled data enables different processing techniques to be applied, such as varying of the integration period, or making use of the Doppler and phase information to filter the code phase measurements. The same data may even contain signals from more than one satellite (depending on antenna beam-width and timing of operation).

Using the GPS receiver for real-time processing of the signals, the 12 channels associated with the nadir-pointing antenna are dedicated to monitoring a single GPS signal. Two approaches may be used for GPS ocean reflectometry metrics:

1) Multiple satellite mode: The 12 nadir channels are allocated to the same 12 GPS satellites as the zenith channels, and are set up to sequentially step through half code-chips around the expected reflection delay every millisecond.

2) Single satellite mode: One channel is assigned to track or monitor the signal near the nominal specular code phase, while the other 11 channels are perturbed from this reference channel in half code-chip or frequency intervals enabling continuous tracking for longer integration times (hence obtain greater gain).

From aircraft altitudes, it has been shown that the code correlation shape has a strong dependence on the wind speed. [4]. The correlation peak is normally triangular, but as the wind speed increases, the overall magnitude reduces, and the tail flattens off. At spaceborne altitudes, it is believed that the shape will flatten off further, and although the absolute signal levels continue to fall, it is still thought that measurements can be taken that will address the Marine navigation requirements. If the significant wave height can be determined to 0.7 metres or better using this technique then GPS ocean reflectometry offers a genuine low cost approach to the traditional altimeter solutions as proposed for e.g. the GANDER mission.

## 4 NANOSATELLITE PLATFORM DESCRIPTION

The SSTL Nanosatellite Applications Platform (SNAP) is a modular multi-mission nanosatellite platform, which has been designed to meet a wide range of missions. The first version, launched in 2000 was triangular in shape. The current proposed structure is essentially a square aluminium honeycomb plate, on which the same spacecraft sub-systems are mounted. It uses body-mounted Al-Al honeycomb solar panels. The separation system is a ring with a pyrotechnic ring charge to provide separation. There are four push-off springs to separate the spacecraft from the launcher.

Space heritage of this spacecraft is assured by using mostly the same sub-systems as SNAP. The system budgets are described in the remainder of this section.

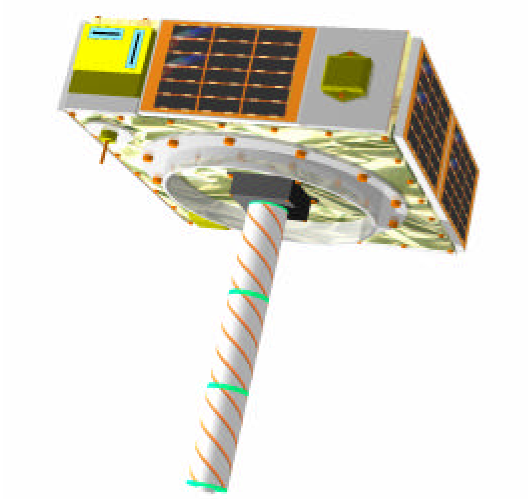

**Figure 9 GPS Ocean Reflectometry Nanosatellite Concept**

The proposed GPS Ocean Reflectometry Nanosatellite mission differs from the SNAP-1 mission through:

- Use the upgraded 128 Mbyte version of the SNAP-1 on-board computer to support the GPS ocean reflectometry experimental payload.
- Replacement of the SNAP-1 GPS SGR-05 receiver with the SGR-10 24 channel GPS receiver.
- Removal of orbit control system – SNAP-1 used a miniature propulsion system to perform in-orbit rendezvous manoeuvres with another spacecraft. This is not felt to be necessary for the purpose and lifetime of the GPS ocean reflectometry pathfinder mission.
- Large directional payload antenna mounted on Earth facing facet.
- Full three axis slewing by adding two reaction wheels
- Overall size increased compared to SNAP to accommodate the SGR GPS payload. This may be exploited to increase the power should this be required (launch and orbit dependent).

Figure 9 depicts the GPS ocean reflectometry nanosatellite platform concept. The payload antenna is Nadir pointing. The attitude control system will rotate the entire spacecraft to point the antenna at the required specular point on the Earth's surface and that required for satisfactory attitude control.

### 4.1 Mass Budget

The preliminary mass breakdown for the nanosatellite is presented in Table 1.

| Subsystem | Mass (kg) |
|---|---|
| Structure & Thermal | 2.6 |
| ADCS | 1.3 |
| Power & Harness | 3.7 |
| Comms | 0.7 |
| Payload Antenna | 1.0 |
| OBC & Data Storage | 1.2 |
| GPS Receiver | 1.0 |
| Subtotal | 9.5 |
| Margin 5% | 0.5 |
| **Total** | **12.0** |

**Table 1 Preliminary Mass Budget**

The value is within the acceptable limits for the proposed structure. Almost 30% of the mass is dedicated to the payload and mission-specific payload support functions. The remaining subsystems are based on SNAP-1 flight proven hardware.

### 4.2 Power Subsystem

Primary power to the satellite is supplied via 4 solar panels and two strings of cells on the space facing facet. The power from the each panel input feeds into a dedicated battery charge regulator (BCR). The outputs of the BCRs are connected the battery, the power distribution module (PDM) and the power conditioning module (PCM) input. From the nominal Nadir pointing mode the orbit average power SSTL is confident that the payload and platform requirements can be met (the final figure is dependent on the operational orbit). The spacecraft can also offpoint to improve the Sun angle on the solar panels. During payload operations the spacecraft points at the specular point on the ocean surface.

### 4.3 Power Budget

The mission power budget is listed in Table 2. The following assumptions have been made:

- The basic platform includes some equipment that is permanently powered. This includes the power system, receivers and some telemetry and telecommand hardware.
- Appropriate duty cycles are assumed. These are highlighted where relevant.
- The on-board computer is active and 75% loaded over a 75% duty cycle.

The total power drawn by the platform and payload amounts to roughly 4.8 watts. This shows the payload and downlink antennas operating during the same orbit, although in practice only one of these would be operational at a time and the orbit average power drawn by the platform would be roughly 4.3 W. This can nominally be met with the solar panels employing high efficiency solar cells. Should an increase in power be required, panel extension may be necessary. The need for this can be determined once the operational orbit parameters are known.

| Subsystem | Power Drain (mW) | Comments |
|---|---|---|
| OBC & Data Storage | 1125 | At 75% activity level |
| S-band downlink | 390 | At 12% duty cycle |
| VHF uplink | 400 | |
| Power Conditioning and Distribution | 510 | |
| BCR and Battery | 510 | |
| ADCS | 1100 | |
| Payload Antenna & GPS Receiver | 500 | Approx. 10% duty cycle |
| Subtotal | 4535 | |
| Margin 5 % | 227 | |
| Total Orbit Av. Power | **4762** | |

**Table 2 Preliminary Power Budget**

### 4.4 ADCS

The nanosatellite is three-axis stabilised using three small momentum wheels positioned along the body axis of the spacecraft. The yaw attitude will be maintained near zero while the roll and pitch angle can be controlled to any reference attitude, enabling rapid slewing which can be exploited to increase coverage of the reflected GPS signals. The nominal spacecraft mode will be Nadir. During payload operations the spacecraft can be rolled and pitched by ±90° to enable acquisition and tracking of reflected GNSS signals from the ocean surface.

The attitude estimation accuracy is better than about 1° in pitch and 2° in roll and yaw. The OBC is used to implement the ADCS software, although a step-down version of attitude determination and control is possible by using the microcontroller in the ADCS module. The orbital position and velocity of the nanosatellite is measured in real time using the SGR GPS receiver, which offers roughly 10 metres (1 sigma) position accuracy.

### 4.5 Data Budget

The 128 Mbyte memory on the OBC accepts the two 5.71 Mbps lines of payload data, plus the position velocity, time and raw measurements from the zenith antenna (Table 3). Roughly 1.5 minutes of uncompressed raw data can be stored on-board. The nanosatellite S-band downlink can operate up to 500 kbps. The S-band transmitter supports BPSK and QPSK modulation schemes, which are in-orbit selectable. Assuming maximum available data rate enables 1.5 minutes worth of data to be downloaded from the nanosatellite in less than a day, if a single ground station at Guildford with roughly six 8-minute passes per day is assumed.

| | | |
|---|---|---|
| Zenith antenna | Position, velocity, time and raw measurements from the zenith antenna, gathered over an orbit. | Approx 500 Kbytes |
| Nadir antenna | 1.5 minutes of 2-bit samples at 5.71 Mbps | Approx 128 Mbytes |

**Table 3 Estimated quantity of data for one measurement operation**

## 5 MISSION UPGRADE OPTIONS

The mission described here has been optimised to minimise the cost and schedule by employing as far as possible the heritage and design of SNAP-1. This inevitably places some constraints on the effectiveness of the mission, which could be mitigated given a longer schedule and an increased cost. Platform options that may be considered include:

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- Increased Redundancy: Currently a single-string approach to the satellite is adopted, as on SNAP-1. Adding some redundancy (for example, two receivers) would increase robustness of the design and operations.
- Orbit Control: A miniature on-board propulsion system for orbit maintenance has been proven on SNAP-1. If there were sufficient advantages in fixing the orbit to a repeat ground-track (such as TOPEX-Poseidon follows) then this could potentially be achieved on the nanosatellite.

Subject to detailed budget analysis, certain miniaturised ESA demonstration payloads may also be flown, such as CMOS cameras, for example. The nanosatellite offers a number of interface options for external payloads in addition to the platform's CAN bus. These include an interface module providing 16 TTL digital I/O plus 8 analogue input and 8 analogue output lines. RS232/422 connections from the OBC could be made available upon request.

The SGR-10 GPS receiver could be upgraded quite simply to the SGR-20, which accepts four GPS antenna inputs. This would enable the potential for a GPS attitude determination with the incorporation of two additional GPS antennas on the nanosatellite. Clearly the mechanical constraints on the platform would limit the baselines and the antenna choice, but options may be considered that make use of miniaturized antennas, or special antenna mounting arrangements.

Opportunities also exist for making use of the GPS receiver to monitor in-band interference in the GPS L1 band around the globe. The flexible software environment of the OBC will permit experimentation with in-orbit IP communications and LINUX implementation.

Depending on programme size, several nanosatellites could be launched at the same time to provide increased capability, and wider coverage of the oceans.

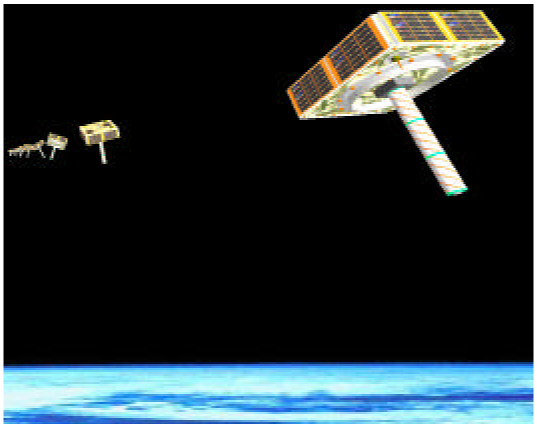

**Figure 10 GPS Ocean Reflectometry Nanosatellite Constellation Concept**

## 6 SUMMARY AND CURRENT STATUS

A nanosatellite mission has been described in which would provide low cost validation of the GPS reflectometry concept. The platform is based on the successful SNAP-1 satellite that was launched in June 2000. The SGR-10 GPS receiver would be able to sample the GPS reflections received by the LHCP antenna from the predicted specular point on the sea surface. In the first instance the satellite DHU will be able to download 1.5 minutes of this data in less than a day so that the sea state information can be extracted on the ground. It is expected that the algorithms that extract this sea state information can later be coded into the receiver such that the sea state information can be transmitted directly from the satellite. This would allow for transmission of sea state information each time a specular data is received.

SSTL recently has been modifying the software in the SGR GPS receiver to permit the on-board processing of reflected GPS signals. As a result various simulations have been performed to aid development of specular point selection, and spaceborne tests have been performed using SSTL's UoSAT-12 minisatellite.

## 7 ACKNOWLEDGEMENTS

Funding to develop the SGR software has been provided by the BNSC under the NEWTON programme.

## 8 REFERENCES

[1] C. Underwood et al, "SNAP-1: A Low Cost Modular COTS-Based Nano-Satellite – Design, Construction, Launch and Early Operations Phase", 15th AIAA / USU Conference on Small Satellites

[2] M. Martin-Neira, "A Pas sive Reflectometry and Interferometry System (PARIS): Application to Ocean Altimetry", ESA Journal 1993, Vol. 17.

[3] J.L. Garrison, S.J.Katsberg, M.I.Hill, "Effect of Sea Roughness on Bistatically Scattered Range Coded Signals from the Global Positioning System", Geophysical Research Letters, 25:2257-2260, 1998.

[4] Komjathy A., et al. "GPS Signal Scattering from Sea Surface: Comparison between Experimental Data and Theoretical Model", 5th Int. Conf Remote Sensing for Marine and Coastal Environments, San Diego, Oct 98.

[5] http://www.bnsc.gov.uk/index.cfm?nid=10940

[6] M. Armatys. Estimation of Sea Surface Winds Using Reflected GPS Signals. PhD thesis, University of Colorado, July 2001